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THE DISTANCES OF THE HEAVENLY BODIES[1]

A YEAR ago our retiring president took the members of the society into his confidence as follows:

> Cognizant of the fact that my election to the presidency of the Philosophical Society a year ago obligated me to give an address of some sort one year later, I confidently waited for the inspiration that I felt would suggest a fitting subject for the occasion. The expected inspiration did not, however, materialize.

Undoubtedly because of that fact, and out of the goodness of his heart, towards the close of his address he turned to the present speaker, then presiding, and said:

> I have said nothing whatever about the determination of the distances between the planets nor of the units used by astronomers in reckoning distances of the stars. . . . They form, so to speak, other chapters of the subject which I shall leave to some future ex-president of our society.

This call, I suppose, was intended to take the place of an inspiration, and, wherever I have gone during the past twelve months the call has ever been ringing in my ears. The subject of the evening is presented therefore not as a matter of choice, but from compulsion.

Before any attempt was made by the ancients to determine the distance from the earth of any celestial body, we find them arranging these bodies in order of distance very much as we know them to-day, assuming that the more rapid the motion of a body among the stars the less its distance from the earth; the stars, that were supposed to have no relative motions, were assumed to be the most distant objects.

[1] Address of the president of the Philosophical Society of Washington, March 4, 1916.

The first attempt to assign definite relative distances to any two of the bodies was probably that of Eudoxus of Cnidus who, about 370 B.C., supposed, according to Archimedes, that the diameter of the sun was nine times greater than that of the moon, which is equivalent to saying, since the sun and the moon have approximately the same apparent diameter, that the distance of the sun from the earth is nine times greater than that of the moon.

A century later, about 275 B.C., Aristarchus of Samos gave a method of determining the relative distances of the sun and moon from the earth as follows: When the moon is at the phase, first quarter or last quarter, the earth is in the plane of the circle which separates the portion of the moon illuminated by the sun from the non-illuminated part, and the line from the observer to the center of the moon is perpendicular to the line from the center of the moon to the sun. (Diagram shown.) If, at this instant, the angular separation of the sun and moon is determined, one of the acute angles of a right-angle triangle—sun, moon and earth—is known, from which can be deduced the ratio of any two of the sides, as, for instance, the ratio of the distance from the earth to the moon to that from the earth to the sun. Aristarchus gives the value of this angle as differing from a right angle by only one thirtieth of that angle, *i. e.*, it is an angle of 87°, from which follows that the distance from the earth to the sun is nineteen times that from the earth to the moon. This method of Aristarchus is theoretically correct, but, in determining the angle at the earth as being 3° less than a right angle, he made an error of about 2° 50′.

Hipparchus, who lived about 150 B.C. and was called by Delambre the true father of astronomy, attacked the problem of the distances of the sun and moon through a study of eclipses. Assuming in accordance with the result of Aristarchus that the sun is nineteen times as far from the earth as the moon, having determined the diameter of the earth's shadow at the distance of the moon and knowing the angular diameter of the moon, he found 3′ as the sun's horizontal parallax. By the sun's parallax is meant the angle at the sun subtended by the earth's semi-diameter and if $a =$ the semi-diameter of the earth, $\Delta =$ the distance to the sun, and $\pi =$ sun's horizontal parallax, the relation between these quantities is expressed by the equation (diagram shown).

$$\text{Sin } \pi = a/\Delta.$$

The next attempt to determine the distance of a heavenly body was made about A.D. 150 by Claudius Ptolemy, the last of the ancient astronomers, and one whose writings were considered the standard in things astronomical for fifteen centuries. To determine the lunar parallax, he resorted to direct observations of the zenith distance of the moon on the meridian, comparing the result of his observations with the position obtained from the lunar theory. He determined the parallax when the moon was nearest the zenith, and also when it crossed his meridian at its farthest distance from the zenith. From his observations he obtained results varying from less than 50 per cent. of the true parallax (57′.0) to more than 150 per cent. of that value. According to Houzeau the definitive result of Ptolemy's work is 58.′7.

It is thus seen that the astronomers of two thousand years ago had a fairly accurate knowledge of the distance of the moon from the earth, but an entirely erroneous one of the distance of the sun, the true distance being something like twenty times that assumed by them. This value of the distance of the sun from the earth was accepted for nineteen centuries, from Aristarchus to Kepler, having been deduced

anew by such men as Copernicus and Tycho Brahe.

With the announcement by Kepler, early in the seventeenth century, of his laws of planetary motion, it became possible to deduce from the periodic times of revolution of the planets around the sun their relative distances from that body, and thus to determine the distance of the sun from the earth, by determining the distance or parallax of one of the planets.

From observations of Mars, Kepler obtained the distance of the sun from the earth as about three times that accepted up to his time. His value, however, was but one seventh of the true distance. About fifty years later Flamsteed and Cassini working independently, and using the same method as that employed by Kepler, obtained for the first time approximately the correct value of the distance of the sun from the earth. In a letter, dated November 16, 1672, to the publisher of the *Philosophical Transactions,* Flamsteed says:

> September last I went to Townley. The first week that I intended to have observed ♂ there with Mr. Townley, I twice observ'd him, but could not make two Observations, as I intended, in one night. The first night after my return, I had the good hap to measure his distances from two Stars the same night; whereby I find, that the Parallax was very small; certainly not 30 seconds: So that I believe the Sun's Parallax is not more than 10 seconds. Of this Observation I intend to write a small Tract, when I shall gain leisure; in which I shall demonstrate both the Diameter and Distances of all the Planets by Observations; for which I am now pretty well fitted.

During the two and a half centuries since Flamsteed's determination there have been more than a hundred determinations of the solar parallax by various methods. In the method used by Flamsteed, the rotation of the earth is depended upon to change the relative position of the observer, the center of the earth, and Mars. (Diagram shown.) Another method is to establish two stations widely separated in latitude, and in approximately the same longitude. At one station, the zenith distance of Mars will be determined as it crosses the meridian north of the zenith; at the other station, the zenith distance will be determined as it crosses the meridian south of the zenith. The sum of the two zenith distances minus the difference in latitude between the two stations will give the displacement of Mars due to parallax. These two methods have been successfully applied to several of the asteroids whose distances from the sun are very near that of Mars.

The nearest approach of Venus to the earth is during her transit across the face of the sun, and these occasions, four during the last two centuries, have been utilized to determine the solar parallax. Here as in the case of Mars two different methods may be used, either by combining observations at two stations widely separated in latitude, or at two stations widely separated in longitude. (Diagrams shown.)

The methods just described for obtaining the solar parallax, the geometrical methods, were made available, as has been said, by the discovery of Kepler's laws of planetary motion. Newton's discovery of the law of gravitation gave rise to another group of methods, designated as gravitational methods. The best of these is probably that in which the distance of the sun from the earth is determined from the mass of the earth, which, in turn, is determined from the perturbative effect of the earth upon Venus and Mars. This method is long and laborious, but its importance lies in the fact that the accuracy of the result increases with the time. Professor C. A. Young says:

> This is the "method of the future," and two or three hundred years hence will have superseded all the others—unless indeed it should appear that bodies at present unknown are interfering with the movements of our neighboring planets, or un-

less it should turn out that the law of gravitation is not quite so simple as it is now supposed to be.

A third group of methods of determining the distance of the sun from the earth, called the physical methods, depends upon the determination of the velocity of light in conjunction either with the time it takes light to travel from the sun to the earth obtained from observations of the eclipses of Jupiter's satellites, or with the constant of aberration derived from observations of the stars.

In August, 1898, Dr. Witt, of Berlin, discovered an asteroid, since named Eros, which was soon seen to offer exceptional opportunity for the determination of the solar parallax, as at the very next opposition, in November, 1900, it would approach to within 30,000,000 miles of the earth. At the meeting of the Astrographic Chart Congress in Paris in July, 1900, it was resolved to seize this opportunity and organize an international parallax campaign. Fifty-eight observatories took part in the various observations called for by the general plan. The meridian instruments determined the absolute position of Eros from night to night as it crossed the meridians of the various observatories; the large visual refractors measured the distance of Eros from the faint stars near it, at times continuing the measures throughout the entire night; and the photographic equatorials obtained permanent records of the position of Eros among the surrounding stars. In addition long series of observations had to be made to determine the positions of the stars to which Eros was referred.

When several years had elapsed after the completion of the observations, and no general discussion of all the material had been provided for, Professor Arthur R. Hinks, of Cambridge, England, volunteered for the work. The undertaking was truly monumental. He first formed a catalogue of the 671 stars which had been selected by the Paris Congress for observation as marking out the path of Eros from a discussion of the results obtained by the meridian instruments and from the photographic plates. This done, with these results as a basis, a larger catalogue of about 6,000 stars had to be formed from measures on the photographic plates. He was then ready to commence the discussion of the observations of Eros itself. From 1901 to 1910 there appeared in the *Monthly Notices* of the Royal Astronomical Society eight articles covering 135 pages giving the results of his labors.

From a discussion of all the photographic observations he obtained a solar parallax of $8''.807 \pm 0''.0027$, a probable error equivalent to an uncertainty of about 30,000 miles in the distance to the sun.

From a discussion of all the micrometric observations he obtained $8''.806 \pm 0''.004$.

The observations with the meridian instruments gave $8''.837 \pm 0''.0185$, a determination relatively much weaker than either of the others.

A parallax of $8''.80$, the value adopted for all the national almanacs twenty years ago, corresponds to a distance of 92,900,000 miles. At present it seems improbable that another parallax campaign will be undertaken before 1931, when Eros approaches still nearer to the earth, its least distance at that time being about 15,000,000 miles.

APPROXIMATE DISTANCES FROM EARTH TO SUN AS ACCEPTED AT VARIOUS TIMES

Date.	Distance, Miles.
275 B.C. to A.D. 1620	4,500,000
1620 Kepler	13,500,000
1672 Flamsteed	81,500,000
1916	92,900,000

When Copernicus proposed that the sun is the center of the solar system and all the planets including the earth revolve around the sun, it was at once seen that such a mo-

tion of the earth must produce an annual parallax of the stars. Tycho Brahe rejected the Copernican system because he could not find from his observations any such parallax. However, the system was generally accepted as the true one and the determination of stellar parallax or the distance of the stars became a live subject. Picard in the latter half of the seventeenth century, using a telescope and a micrometer in connection with his divided circle, showed an annual variation in the declination of the pole star amounting to 40″. In 1674 Hooke announced a parallax of 15″ for γ Draconis. About this same time Flamsteed announced a parallax of 20″ for α Ursæ Minoris, but J. Cassini showed that the variations in the declination did not follow the law of the parallax.

The period which we have now reached is so admirably treated by Sir Frank W. Dyson, Astronomer Royal, in his Halley lecture delivered at Oxford on May 20, 1915, that I ask your indulgence while I quote rather freely from that source.

Thus in Halley's time, it was fairly well established that the stars were at least 20,000 or 30,000 times as distant as the sun. Halley did not succeed in finding their range, but he made an important discovery which showed that three of the stars were at sensible distances. In 1718 he contributed to the Royal Society a paper entitled "Considerations of the Change of the Latitude of Some of the Principal Bright Stars." While pursuing researches on another subject, he found that the three bright stars—Aldebaran, Sirius and Arcturus—occupied positions among the other stars differing considerably from those assigned to them in the "Almagest" of Ptolemy. He showed that the possibility of an error in the transcription of the manuscript could be safely excluded, and that the southward movement of these stars to the extent of 37′, 42′ and 33′—*i. e.*, angles larger than the apparent diameter of the sun in the sky—were established. . . .

This is the first good evidence, *i. e.*, evidence which we now know to be true, that the so-called fixed stars are not fixed relatively to one another. It is the first positive proof that the distances of the stars are sensibly less than infinite.

At the time of the appearance of Halley's paper there was coming into notice a young astronomer, James Bradley, then twenty-six years old. He was admitted to membership in the Royal Society the same year that Halley's paper was presented. He was exceedingly eager to attack the problem of the distances of the stars. At length the opportunity presented itself. To quote again from Sir Frank Dyson:

Bradley designed an instrument for measuring the angular distance from the zenith, at which a certain star, γ Draconis, crossed the meridian. This instrument is called a zenith sector. The direction of the vertical is given by a plumb-line, and he measured from day to day the angular distance of the star from the direction of the vertical. From December, 1725, to March, 1726, the star gradually moved further south; then it remained stationary for a little time; then moved northwards until, by the middle of June, it was in the same position as in December. It continued to move northwards until the beginning of September, then turned again and reached its old position in December. The movement was very regular and evidently not due to any errors in Bradley's observations. But it was most unexpected. The effect of parallax—which Bradley was looking for—would have brought the star farthest south in December, not in March. The times were all three months wrong. Bradley examined other stars, thinking first that this might be due to a movement of the earth's pole. But this would not explain the phenomena. The true explanation, it is said, although I do not know how truly, occurred to Bradley when he was sailing on the Thames, and noticed that the direction of the wind, as indicated by a vane on the mast-head, varied slightly with the course on which the boat was sailing. An account of the observations in the form of a letter from Bradley to Halley is published in the *Philosophical Transactions* for December, 1728:

"When the year was completed, I began to examine and compare my observations, and having pretty well satisfied myself as to the general laws of the *phenomena*, I then endeavored to find out the cause of them. I was already convinced that the apparent motion of the stars was not owing to the nutation of the earth's axis. The next

thing that offered itself was an alteration in the direction of the plumb-line with which the instrument was constantly rectified; but this upon trial proved insufficient. Then I considered what refraction might do, but here also nothing satisfactory occurred. At length I conjectured that all the *phenomena* hitherto mentioned, proceeded from the progressive motion of light and the earth's annual motion in its orbit. For I perceived that, if light was propagated in time, the apparent place of a fixed object would not be the same when the eye is at rest, as when it is moving in any other direction than that of the line passing through the eye and the object; and that, when the eye is moving in different directions, the apparent place of the object would be different."

When Bradley's observations of γ Draconis were corrected for aberration, they showed, according to himself, that the parallax of that star could not be as much as $1''.0$, or that the star was more than 200,000 times as distant from the earth as the sun.

On December 6, 1781, there was read before the Royal Society a paper by Mr. Herschel, afterwards Sir William, on the "Parallax of the Fixed Stars." We read:

The method pointed out by Galileo, and first attempted by Hook, Flamstead, Molineaux and Bradley, of taking distances of stars from the zenith that pass very near it, though it failed with regard to parallax, has been productive of the most noble discoveries of another nature. At the same time it has given us a much juster idea of the immense distance of the stars, and furnished us with an approximation to the knowledge of their parallax that is much nearer the truth than we ever had before. . . .

In general, the method of zenith distances labours under the following considerable difficulties. In the first place, all these distances, though they should not exceed a few degrees, are liable to refractions; and I hope to be pardoned when I say that the real quantities of these refractions, and their differences, are very far from being perfectly known. Secondly, the change of position of the earth's axis arising from nutation, precession of the equinoxes, and other causes, is so far from being completely settled, that it would not be very easy to say what it exactly is at any given time. In the third place, the aberration of light, though best known of all, may also be liable to some small errors, since the observations from which it was deduced laboured under all the foregoing difficulties. I do not mean to say, that our theories of all these causes of error are defective; on the contrary, I grant that we are for most astronomical purposes sufficiently furnished with excellent tables to correct our observations from the above mentioned errors. But when we are upon so delicate a point as the parallax of the stars; when we are investigating angles that may, perhaps, not amount to a single second, we must endeavor to keep clear of every possibility of being involved in uncertainties; even the hundredth part of a second becomes a quantity to be taken into consideration.

Herschel then proceeds to advocate selecting pairs of stars of very unequal magnitude and whose distance apart is less than five seconds, and making very accurate micrometric measures of this distance from time to time. The first condition should give, in general, stars very unequally distant from the earth, so that the changing perspective as the earth revolves in her orbit would give a variation of the apparent distance between the stars, while the small distance, less than five seconds, would eliminate from consideration entirely any effect upon this distance of the uncertainties in refraction, precession, nutation, aberration, etc. Herschel had already commenced the cataloguing of such double stars and in January, 1782, submitted to the Royal Society a catalogue of 269. This work did not enable Herschel to determine the distance of the stars but did enable him to demonstrate that there exist pairs of stars in which the two components revolve the one around the other. In twenty years he had found fifty such pairs.

Coming forward another generation, that is, to a time a little less than a hundred years ago, we find Pond, then Astronomer Royal, writing

The history of annual parallax appears to me to be this: in proportion as instruments have been imperfect in their construction, they have misled observers into the belief of the existence of sen-

sible parallax. This has happened in Italy to astronomers of the very first reputation. The Dublin instrument is superior to any of a similar construction on the continent; and accordingly it shows a much less parallax than the Italian astronomers imagined they had detected. Conceiving that I have established, beyond a doubt, that the Greenwich instrument approaches still nearer to perfection, I can come to no other conclusion than that this is the reason why it discovers no parallax at all.

Within fifteen years after this statement by Pond, observations had been obtained which showed a measurable parallax of three different stars. The announcements of these results, each by a different astronomer, were practically simultaneous.

W. Struve, using a filar micrometer, determined the distance of α Lyræ from a small star about 40″ distant on 60 different days over a period of nearly three years. He obtained a parallax of $0''.262 \pm 0.''025$. Bessel, using his heliometer, determined the distance of 61 Cygni from two small stars distant about 500″ and 700″, respectively. He obtained for this star a parallax of $0''.314 \pm 0''.020$. Henderson, using determinations of the position of α Centauri by meridian instruments, deduced a parallax of $1''.16 \pm 0''.11$. All three of these results were announced in the winter of 1838–39, and indicate that the three stars are distant from the earth about 750,000, 650,000 and 200,000 times the distance of the sun from the earth.

The accompanying table exhibits the observed displacement of 61 Cygni by monthly means as given by Main from Bessel's observations. The last column gives the computed displacement on the assumption of a parallax of $0''.314$. The reality of the parallax is seen at a glance.

In 1888, fifty years after the first determination of what we now know to be a true stellar parallax, Young, in his General Astronomy, gives, in a list of known stellar parallaxes, 28 stars and 55 separate determinations. Within the next ten years the number of stars whose parallaxes had been determined about doubled, due principally to the work of Gill and Elkin.

PARALLAX OF 61 CYGNI

Mean Date	Observed Displacement ″	Computed from 0″.514 ″
1837 August 23	+ 0.20	+ 0.18
September 14	+ 0.10	+ 0.08
October 12	+ 0.04	— 0.05
November 22	— 0.21	— 0.22
December 21	— 0.32	— 0.27
1838 January 14	— 0.38	— 0.27
February 5	— 0.22	— 0.23
May 14	+ 0.24	+ 0.20
June 19	+ 0.36	+ 0.28
July 13	+ 0.22	+ 0.28
August 19	+ 0.15	+ 0.19
September 19	+ 0.04	+ 0.06

Probably the most extensive piece of stellar parallax work in existence is that with the Yale heliometer. The results to date were published in 1912 and contained the parallaxes of 245 stars, the observations extending over a quarter of a century, the entire work having been done by three men, Elkin, Chase and Smith. In selecting a list of stars for parallax work an effort is made to obtain stars which give promise of being nearer than the mass of stars. At first the brighter stars were selected, and then those with large proper motions. The Yale list of 245 stars contains all stars in the northern heavens whose annual proper motion is known to be as much as $0''.5$. Of these 245 stars, 54 are given a negative parallax. A negative parallax does not mean, as some one has expressed it, that the star is "somewhere on the other side of nowhere," but such a result may be attributed to the errors of observation or to the fact that the comparison stars are nearer than the one under investigation. It is safe to say, however, that

somewhat more than half of the 245 stars have a measurable parallax.

Another series of stellar parallax observations, comparable in extent with the one just mentioned, is that of Flint at the Washburn Observatory. This series includes 203 stars and extended from 1893 to 1905. These observations were made with a meridian circle, but not after the method of a century ago. The observations were strictly differential, the general plan being to select two faint comparison stars, one immediately preceding and the other immediately following the parallax star, and to determine the difference in right ascension, the observation of the three stars occupying about 5 minutes. Here as in the case of the Yale heliometer work a large proportion of the resulting parallaxes are negative; somewhat more than half, however, were found to have a measurable parallax. The average probable error of a parallax was the same in each of these two pieces of work, about 0″.03. The progress of the work during the last two or three generations is given in the following table, which contains also a brief statement of the discoveries made during the preceding century, due chiefly to efforts to measure stellar parallaxes.

APPROXIMATE NUMBER OF KNOWN STELLAR PARALLAXES

Date	Astronomer	Number of Stars with Known Parallaxes	Discoveries
1718.	Halley	No parallax	Proper motion.
1728.	Bradley	No parallax	Aberration.
1750.	Bradley	No parallax	Nutation.
1790.	Herschel	No parallax	True binary systems.
1838.		3	
1888.		28	
1898.		50 to 60	
1916.		200 to 300	

A generation ago photography entered the field of stellar parallax work, and has outdistanced all the previously employed methods for efficiency. In 1911, two publications appeared giving the results of photographic stellar parallax work, one by Russell, giving the parallaxes of forty stars from photographs taken by Hinks and himself at Cambridge, England, the other by Schlesinger, giving the parallaxes of twenty-five stars from photographs taken mostly by himself at the Yerkes Observatory, Williams Bay, Wisconsin. In speaking of these two series of observations, Sir David Gill said,

> On the whole, the Cambridge results, when a sufficient number of plates have been taken, and when the comparison stars are symmetrically arranged, give results of an accuracy which, but for the wonderful precision of the Yerkes observations, would have been regarded as of the highest class.

Schlesinger has shown that with a telescope of the size and character of the Yerkes instrument

> the number of stellar parallaxes that can be determined per annum, with an average probable error of 0.″013, will in the long run be about equal to the number of clear nights available for the work.

In other words, the Yerkes 40-inch equatorial used photographically determines stellar parallaxes with one tenth the labor required with a heliometer and with twice the accuracy.

In July, 1913, stellar parallax work was undertaken with the 60-inch reflector of the Mount Wilson Solar Observatory, and at the meeting of the American Astronomical Society at San Francisco in August, 1915, a report on that work was made. The parallaxes of thirteen stars had been determined, with a maximum probable error of 0″.010 and an average probable error of less than 0″.006, giving twice the accuracy of the Schlesinger results with the Yerkes 40-inch and from three to five times that obtained fifteen years ago. What may we not expect when the 100-inch reflector gets to work on Mt. Wilson.

At the meeting of the American Astronomical Society to which reference has just been made, two other observatories reported upon their stellar parallax work. Lee and Joy of the Yerkes Observatory reported the parallaxes of nine stars with a maximum probable error of 0''.014 and an average probable error of 0''.010, and Mitchell, of Leander McCormick Observatory, reported the parallaxes of eleven stars with a maximum probable error of 0''.012 and an average probable error of 0''.009.

The progress made in the accuracy of parallax results is shown at a glance in the following table.

THE ACCURACY OF STELLAR PARALLAX DETERMINATIONS

Date	Instrument	Probable Error	Observers
1838........	Dorpat refractor	0''.025	Struve.
1838........	Königsberg heliometer	0.02	Bessel.
1880–1898	Cape heliometer	0.017	Gill and assistants.
1888–1912	Yale heliometer	0.03	Elkin, Chase, and Smith.
1893–1905	Washburn meridian circle	0.03	Flint.
	Photographic Results		
1910........	Yerkes refractor	0.013	Schlesinger.
1915........	Yerkes refractor	0.010	Lee and Joy.
1915........	Leander McCormick refractor	0.009	Mitchell.
1915........	Mt. Wilson 60-inch reflector	0.006	Van Maanan.

From these results it appears that any star whose parallax is as much as 0''.02, *i. e.*, whose distance from the earth is less than ten million times that from the earth to the sun, should give a positive result when subjected to the treatment now employed in parallax investigations, and as eight or ten observatories are devoting their energies to stellar parallax work at present, the combined programs containing over 1,000 different stars, we ought to have soon lists of at least a few thousand stars whose parallaxes are known where our present ones contain but a few hundred.

W. S. EICHELBERGER
U. S. NAVAL OBSERVATORY

METHODS OF TEACHING ELECTRICAL ENGINEERING[1]

IN the American engineering schools must be recognized professional schools of distinctly advanced grade corresponding to the schools of the more ancient professions of medicine, law and theology. With marked sympathy for artisanship in its most useful forms, their practises and ideals are fully distinct from schools of skilled artisanship such as are in certain countries known as engineering schools; and the preparatory studies required to make students eligible to enter their courses of instruction definitely contain much work in mathematics and the sciences, in addition to an optional range of studies in the modern languages, economics and civics, history and the classics. That is, the American engineering schools are professional schools of university order, as the term university is known internationally. This form of the engineering schools in America is the result of experience and development, which has brought them to educational characteristics much resembling those of the Ecole des Ponts et Chaussees and the Ecole Polytechnique of Paris.

Originating with the third decade of the nineteenth century, the earlier American engineering schools first treated of what we now term "civil engineering," and "mechanical engineering" and "mining engineering" were later joined to the fixed curricula. It was not until 1882 that a formal course of "electrical engineering" was established, and curiously enough, this was done independently and almost

[1] Pan-American Scientific Congress, Washington, D. C., January 4, 1916.